MULTIHOP COMMUNICATION IN RELAY ENHANCED IEEE 802.16 NETWORKS

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ABSTRACT

The introduction of relay stations into metropolitan area networks allows providing ubiquitous broadband access economically to everyone, even to subscribers in remote places. IEEE 802.16, also known as WiMAX, is one of the most promising technologies that currently integrate relays for multihop communication. Such a relay enhanced IEEE 802.16 network can provide ubiquitous radio coverage, achieve high QoS requirements, and it can be economically deployed and operated. This paper presents two concepts to integrate multihop communication into the IEEE 802.16 system. The first concept follows a centralized approach where the base station has full control over the relay-enhanced cell. The second concept follows a semi-distributed approach where a relay station controls the associated subscriber itself. Both concepts are standard-compliant so that legacy subscriber stations can participate without modification.

I. INTRODUCTION

One of the major challenges for the telecommunication community is to provide diverse broadband services everywhere. IEEE 802.16 provides broadband access with performances similar to wired xDSL systems, which surpass current 3G mobile data rates. IEEE standard 802.16 forms the basis of the WiMAX certified technology. [1] [2] [3]

Every wireless system suffers from challenging radio propagation characteristics, so does WiMAX. The achievable signal-to-noise ratio (SNR) and therewith the data rate decreases with an increasing link distance. This results in low SNR at the cell border. Shadowing, which leads to non line-of-sight (NLOS) communication, further reduces the perceived signal quality. The introduction of relay stations may significantly enhance the link quality leading to throughput enhancements and coverage extensions [4]. Thus, relays allow providing ubiquitous broadband access economically to everyone, even to subscribers in remote places. Such a relay enhanced IEEE 802.16 network can provide ubiquitous radio coverage under challenging environmental conditions, achieve high QoS requirements, and it allows for efficient frequency reuse. Furthermore, an economic and scalable deployment and operation is possible, since the network can be flexibly adapted to changing users' behavior or environmental conditions.

Several multihop concepts for frame-based MAC protocols have been developed so far. The wireless LAN standard HiperLAN/2 (H/2) contains a direct mode that allows terminals to communicate directly. The H/2 access point (AP) is coordinating the access, so both terminals must be in the coverage area of the AP's broadcast channel [5]. Another concept, called the beacon concept, relies on the H/2 option for sector antennas, where an AP transmits the broadcast messages and the following MAC frame through each sector antenna sequentially [6]. The third proposal, the subframe concept, realizes multihop communication without special standard options. The AP allocates periods within its MAC frame for relay stations. The relay station can use these periods to act as an AP, thus generating an individual MAC frame (called subframe) for the terminals that are associated to the relay [7].

The IEEE 802.16 mesh mode is an optional feature of the standard. Like the H/2 direct mode, traffic can be routed directly between subscriber stations (SSs). The mesh mode replaces the point to multipoint (PMP) frame structure [1]. Thus, legacy 802.16 stations are not able to communicate with such a mesh network. The Task Group IEEE 802.16j wants to overcome these limitations. It aims at specifying enhancements for a mobile multihop operation without further modifications to SSs. Thus, the frame structure shall be PMP compatible and the MAC management procedures, such as association or handover, shall not be modified. Unlike the 802.16 mesh mode, the task group aims at a tree-based deployment only.

According to the requirements of the IEEE 802.16j task group, this paper presents two concepts to support multihop communication in 802.16 networks. It follows the forwarding principle decode and forward, in which a relay decodes the received data packets, processes them in the MAC layer, e.g., for ARQ operation, and forwards them on the next hop. The concepts utilize time domain forwarding, where packets are forwarded on the same frequency channel. Thus, the relays have to be equipped with only one transmit and receive chain. Although the presented concepts are based on OFDM, they can be extended to OFDMA, which is the target PHY layer in the 802.16j task group. Only the control elements, for instance, the DL- and UL-MAP have to be adapted. The principle frame structure remains valid.

II. IEEE 802.16 MAC FRAME

IEEE 802.16 supports a frame-based transmission. Figure 1 illustrates the frame structure of the OFDM PHY layer operating in TDD mode. Each frame consists of a DL subframe and an UL subframe. Subframes are separated by gaps, which allow stations to switch their PHY processors between transmit and receive states. The partitioning between DL and UL may vary dynamically to efficiently handle an asymmetric traffic load.

DL subframes start with the periodic broadcast of control information. This phase is composed of the DL preamble, the frame control header (FCH) and the first DL burst. SSs use the periodic DL preamble for synchronization and they

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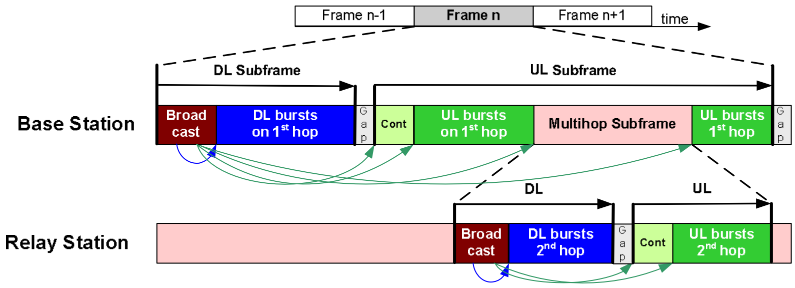

Figure 2: Multihop Subframe Embedded in an 802.16 MAC Frame

perceive the current frame duration as the time interval between two consecutive DL preambles. The frame duration, which may be chosen between 2.5 and 20 ms, is fixed during normal operation. The FCH and the MAC management messages included in the first DL burst define the access to the DL and UL channel, respectively. The arrows in Figure 1 indicate the references of the DL- and UL-MAP to the corresponding DL- and UL bursts. The following DL bursts are made up of MAC packet data units (PDUs) scheduled for DL transmission.

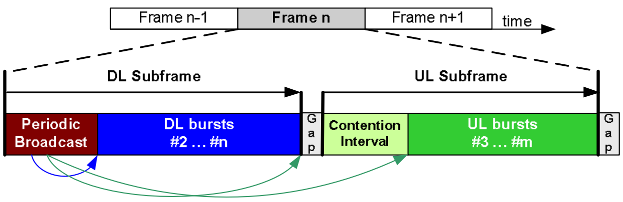

Figure 1: MAC frame structure

The UL subframe consists of contention intervals and one or multiple UL bursts. The base station (BS) schedules slotted contention intervals for initial ranging and for bandwidth request purposes. Initial ranging slots allow SSs to enter the system. UL bursts contain PDUs transmitted by SSs that are scheduled for UL transmission. A more detailed description of the 802.16 frame structure can be found in [1] [3].

III. De-Centrally Controlled Relay Stations

This chapter presents a de-centrally controlled relaying approach, in which the relay has full control over the SSs that are associated to it. The entire functionality that is required for the multihop operation is encapsulated in the relay. The BS is not affected. For the BS, a relay appears like an ordinary SS. For SSs the relay appears to be a regular BS. The next sections outline the frame structure and the connection management.

A. Multihop Enabled Subframe Structure

The de-centralized concept extends the H/2 subframe concept [5] and applies it to the 802.16 system. During the multihop subframe interval, the BS does schedule neither DL nor UL traffic. Instead, it dedicates the interval to the control of the relay station. The relay itself builds up an entire MAC frame. This frame, called multihop subframe, is a standard compliant 802.16 MAC frame.

Figure 2 shows the modified 802.16 frame with the embedded multihop subframe. The frame starts with the DL subframe composed of the broadcast phase and DL bursts. The DL bursts contain PDUs transmitted to SSs that are associated to the BS directly. For the BS, the relay appears to be a regular SS to which data packets are transmitted. All DL bursts are specified by means of the DL MAP. Thus, DL bursts serve SSs and relays on the first hop.

The UL subframe starts with a contention interval followed by UL bursts. SSs, which are close to the BS, use these contention slots for network entry or bandwidth requests. The following UL bursts are scheduled for UL transmission of SSs on the first hop. Some of these UL bursts are scheduled for relay stations. Within these bursts, relays can transmit its UL traffic to the BS. Another UL burst is not addressed to UL transmission at all, but it is reserved for the multihop subframe. The broadcast phase specifies this burst by means of a regular UL MAP (indicated by an arrow in Figure 2).

Since the frame structure of the multihop subframe is standard compliant, it is again divided into a DL and an UL subframe. The DL part starts with the broadcast of control information. The corresponding management messages are only relevant for the multihop subframe. As the arrows in Figure 2 indicate, the DL MAP defines access to the second hop DL channel and the UL MAP schedules UL bursts on the second hop. The following DL bursts of the multihop subframe contain PDUs for SSs on the second hop. UL bursts are scheduled for UL data on the second hop. A gap divides the DL and the UL part of the multihop subframe. SSs close to the relay can access the contention slots scheduled at the beginning of the UL part of the multihop subframe to enter the network or to request bandwidth.

Since the broadcast phase must occur periodically, the BS has to schedule the multihop subframe at fixed time intervals. This can be accomplished since 802.16 provides a scheduling service that has been designed to support real-time data streams that generate data packets on a periodic basis. This so-called unsolicited grant scheduling service assigns UL bursts at periodic intervals. A relay can use such a periodic UL burst to establish its multihop subframe. The size and the duration of the burst can be specified by the QoS parameter set associated to the corresponding UL connection.

Thus, SSs that are close to the BS only notice the BS's frame, whereas SSs near the relay observe the relay station's (sub)frame as if it was a regular frame. SSs that perceive both broadcast control phases seem to be between two neighboring cells. Therefore, they will associate to the cell that they receive loudest. The association of SSs to the relay is handled by means of the standard compliant initial ranging procedure.

The subframe concept can be configured so that the multihop subframe appears to be an individual frame. To do so, the multihop subframe is located at the very end of the frame, the length of the multihop subframe is exactly half of the length of the regular frame and the multihop subframe occurs every regular frame. Thus, the main frame and the multihop subframe appear to be two subsequent frames. The experienced frame period is half of the regular frame duration. It seems that every second frame is dedicated to the BS and the frames in between are dedicated to the relay. This configuration equals the Time Sharing Wireless Router concept presented [8]. This configuration allows for synchronized broadcast phases within the whole system. All relays and all BSs of the system, even if they do not provide multihop communication, can transmit their broadcast phase synchronously. Synchronization may be performed by means of Global Positioning System (GPS) signals. If the MAC implementations of BSs and SSs rely on synchronized broadcast phases they will not be confused by the multihop extension. The disadvantage of such a configuration is that it is less flexible and does not allow for an asymmetric partitioning of the regular frame and the multihop subframe.

If the BS is enhanced by more than one relay station, several multihop subframes have to be scheduled in the MAC frame of the BS. If the relay itself is enhanced by another relay, another multihop (sub-)subframe can be embedded in the subframe of the relay. Like this, a three-hop communication can be provided hierarchically.

B. Connection Masquerading

The introduction of relay stations demands for a special connection management at the relay station. The relay has to route traversing packets in DL (away from the BS) and in UL (towards the BS) direction from hop to hop. It has to maintain a control connection to exchange signaling information with the BS and it possibly receives and transmits data packets on its own.

The presented concept of Connection Masquerading follows the de-centrally controlled relaying approach. For the remote SSs the relay provides all necessary procedures to setup transport and management connections so that the relay acts as a regular BS. For the BS, the relay appears to be an ordinary SS, thus it can setup and release transport connections by means of the standard procedures. Beside the transport connections, the relay maintains its management connections.

As an example Figure 3 shows connections of the masqueraded connection management. The relay station (RS) establishes its control connections to the BS. It uses these connections to exchange signaling information, such as connection management or periodic measurement reports. The relay in Figure 3 has also set up transport connections to receive and transmit data packets. On the right side of the relay, the remote SSs have established management and transport connections to the relay station. The contention-based network entry process and the registration of a SS is handled by the relay itself. The backbone network, to which the relay communicates via its transport connections, assists the process of authentication and authorization.

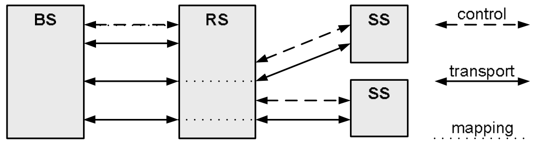

Figure 3: Connection Masquerading

For each transport connection that a SS sets up, the relay opens an associated connection to the BS. Both connections have the same level of QoS. The BS is not aware that the connection corresponds to a remote SS. The relay masquerades the transport connection. It maintains a table to map the connection identifier (CID) of one hop to the CID of the other and vice versa. Figure 3 indicates this mapping. All protocol functionality that maintains a proper packet transmission, such as Automatic repeat request (ARQ), segmentation and reassembly (SAR), or burst profile management, is performed on link basis.

IV. Centrally Controlled Relay Stations

This chapter presents a centrally controlled relaying approach. The BS has full control over the entire relay enhanced cell. The BS directly controls all SSs and all relay stations that are associated to the BS. The complexity of the relay station can be decreased since it just forwards packets from hop to hop. It does not perform any other MAC management procedures to allow for multihop operation.

A. Centralized Multihop Frame Structure

The BS schedules all transmissions, both on the first hop and on subsequent hops. The relay forwards the relevant subset of the control information to the SSs in its subcell. The relay behaves according to the BS's schedule, i.e., it receives, and transmits during bursts scheduled for the corresponding hop.

Figure 4 shows the centralized multihop frame. The BS periodically transmits broadcast control information. The DL preamble indicates the frame start. The following management messages, i.e., FCH and MAPs, specify the entire MAC frame including the bursts scheduled on the second and on any subsequent hop. In order to calculate an appropriate schedule, the BS needs to know which connections of the entire relay enhanced cell are active, which QoS requirements they have, and which connections request UL bandwidth. Having received the broadcast information, the relay filters it and forwards only the relevant subset of information to its subcell. Figure 4 shows that the forwarded MAPs only specify the bursts that are scheduled for data transmission on the second hop. Before the relay starts transmitting the management messages, it sends the periodic DL preamble. Like in the subframe concept, the relay's frame start time has to be strictly periodic.

DL bursts for data transmission follow the broadcast phase. The BS may schedule bursts for any hop. The UL subframe

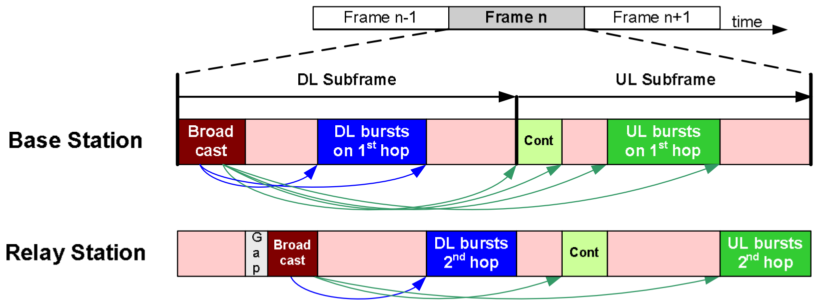

Figure 4: Centralized Multihop MAC Frame

succeeds the DL subframe. Again, phases for data transmission on any hop may be scheduled alternately. This ordering of transmission phases assures that all SSs that are associated either to the BS or to the relay do experience a regular, standard compliant MAC frame. They can associate, open connections, and they can receive and transmit data according to the 802.16 protocol.

B. Connection Mapping

The centrally controlled relay neither manages the SSs' connections nor does it masquerades the transport connections. It just forwards all packets to the BS and SSs, respectively. Figure 5 shows the schematic connection management at the relay station. The relay station itself has control and transport connections to the BS. They carry signaling and data traffic of the relay.

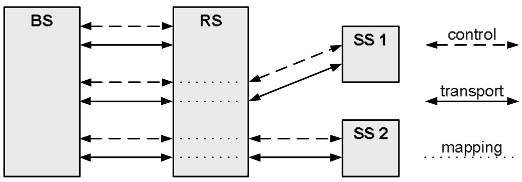

Figure 5: 1-to-1 Mapping of Connections

Furthermore, each second hop connection corresponds to a connection on the first hop. Every time a SSs establishes a management connection to the relay, the relay establishes a corresponding management connections to the BS. Each setup of a SS's transport connection results in a new transport connection of the relay. The mapping is realized by mapping tables.

After the synchronization of a new SS to the relay, it starts the ranging process by sending the ranging request during the relay's contention interval. The relay forwards this message to the BS through its own control connection. The BS processes the request and responds to the SS via the relay. The BS entirely handles the following network entry. However, the standard compliant message exchange does not contain all necessary information for the network entry. Using the 1-to-1 mapping two management CIDs have to be assigned instead of one. One CID is required to identify the connection on the first hop and the other for the second hop. Since the BS schedules both hops, it needs to be aware which CID corresponds to which hop. Setting up transport connections follows the same principle. The relay just forwards the request and the BS assigns two transport CIDs.

All other signaling messages, such as UL bandwidth requests and measurement reports have to be transmitted from the SSs to the BS by means of the relay station. Thus, the BS gathers all necessary information to schedule DL and UL bursts for the relays and for the SSs. It periodically broadcasts the FCH and the MAPs and all nodes behave accordingly.

V. Conclusion

This paper presents two approaches to integrate relay-based multihop communication in the 802.16 standard. Both concepts are standard-compliant so that legacy subscriber stations can participate without modification. The first concept follows a de-centrally-controlled approach where a relay station controls the associated subscriber itself. Only minor changes to the standard are necessary, but the relays require a full featured MAC protocol that is comparable to a BS. The second concept follows a centralized approach where the base station has full control over the relay-enhanced cell. This approach requires more modifications to the standard but the relay stations can be less complex. They only forward packets from one hop to another without performing any management procedures.

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